FEBRUARY, 1926 TECHNICAL BULLETIN 20

AGRICULTURAL EXPERIMENT STATION

KANSAS STATE AGRICULTURAL COLLEGE
MANHATTAN, KANSAS

IMPERIAL BUREAU OF MYCOLOGY
20 JUL 1926

TOMATO WILT INVESTIGATIONS

PRINTED BY KANSAS STATE PRINTING PLANT
B. P. WALKER, STATE PRINTER
TOPEKA 1926
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FIG. 1.—The Kanora tomato, a wilt-resistant variety, grown in heavily infested soil at Cherryvale, 1922. Plants on extreme ends are checks of John Baer variety.

TOMATO WILT INVESTIGATIONS[1]

R. P. WHITE

IMPORTANCE OF THE KANSAS TOMATO CROP

Tomatoes are an important truck crop in Kansas, being exceeded in value of vegetable crops grown only by potatoes, sweet potatoes, and watermelons in the order named. The total value of the tomato crop in 1919, according to the last United States census report,[2] was $341,263. This represents the crop grown on 1,867 acres and 3,937 farms. The per acre value of the tomato crop in this same year was approximately $183. These figures do not take into consideration the inestimable value of the tomatoes grown for home use. The watermelon crop, which exceeds tomatoes in total value, represented a per acre value in the same year of slightly more than $87.

Since 1919 the acreage and value of the tomato crop has been increasing slightly, even though the ravages of several plant diseases have greatly increased. The most serious plant disease is the tomato wilt, caused by the fungous organism, *Fusarium lycopersici* Sacc., a soil-harbored pathogen.

THE FUNGOUS WILT DISEASE

DISTRIBUTION IN KANSAS

Tomato wilt was first observed in Kansas in 1918, but had probably been present in the southeastern part of the state for several years prior to that time, since it was found to be common and locally severe in Neosho and Montgomery counties upon its discovery. Since then it has spread rapidly in the state. From the southeastern corner it has spread steadily northward and westward until at the present time it is known to occur as far north as Wyandotte county on the eastern border and as far west as Harper county on the south. At present the distribution of this disease includes practically the entire southeastern quarter of the state. (Fig. 2.)

LOSSES FROM THE DISEASE

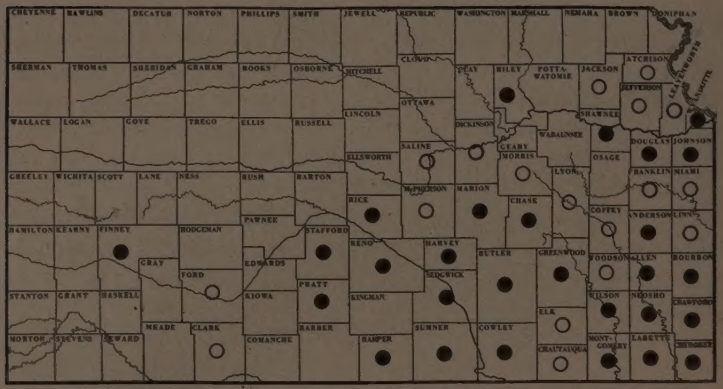
Losses from this disease depend upon seasonal environmental conditions, upon the severity of soil infestation, and upon the variety of tomatoes grown. From an estimated loss of a fraction of 1 per

ACKNOWLEDGMENT.—Credit is due to Prof. L. E. Melchers for the data for the years 1919 to 1921, inclusive. The author also wishes to express his appreciation of many helpful suggestions offered by Professor Melchers throughout the progress of the investigations, and of his critical reading of the manuscript.

1. Contribution No. 242 from the Department of Botany.
2. Fourteenth census of the United States. Vol. VI, part 1, page 730. 1920.

cent in 1918 it has become steadily more severe each year, until in 1924 the loss was conservatively placed at 10 per cent of the entire tomato crop of the state. Basing the production figures on the crop of 1919, the last on which there are records, this would entail an annual loss of over $34,000. Individual losses of 20 to 30 per cent are general in the extreme southeastern part of the state. Losses of approximately 100 per cent have been observed in this region.

The nature of the loss may be twofold; reduced yields and impaired quality of the fruit produced. This disease may kill plants



● *Counties in which tomato wilt is known to exist*
○ *Counties in which tomato wilt is suspected*

FIG. 2.—Map of Kansas showing distribution of tomato wilt.

of the more susceptible varieties early in the season, thereby greatly reducing the crop. The plants of other more resistant varieties do not die immediately, but are so weakened that the fruit does not reach its normal size and ripens prematurely. Such fruit has been found to be lighter in color, less firm, and therefore less desirable both on local markets and for shipping.

SYMPTOMS OF THE DISEASE

Wilt may be distinguished in the field by the yellowing of the lower leaves of the plant, preceded usually by a cessation of growth and accompanied by wilting of the tops. The yellowing of the leaves progresses upward. Wilting is very rapid in susceptible varieties. The leaves of the diseased plants dry up and finally become so brittle that they will crumble when rubbed between the hands. Plants more resistant are usually dwarfed, and the wilting

and yellowing of the leaves takes place more slowly. Plants only slightly diseased may wilt during hot days and recover during the nights. This does not happen more than two or three nights, however, before permanent wilting results. Diseased plants may be pulled from the soil easily due to the decay of many of the roots. When the stems of diseased plants are cut lengthwise, the fibrovascular bundles appear as brown streaks extending up the stems and often into the leaves. The stems of healthy plants are not discolored internally.

This disease is often confused with leaf-spot or "blight," caused by *Septoria lycopersici* Sacc. However, the stems of plants diseased with tomato leafspot are not discolored, while small circular spots appear on the leaves. These spots are brown with gray centers in which appear small, black, pimple-like bodies, the pycnidia or spore cases of the fungus.

SCOPE OF THE PRESENT INVESTIGATIONS

The investigations reported in this bulletin deal with certain environmental influences upon tomato fusarial wilt, and upon the relative resistance of a number of tomato varieties and hybrids to the disease when grown under field conditions in heavily infested soil. The investigations were initiated in 1919 at Cherryvale, Kan., by Prof. L. E. Melchers, plant pathologist of the Agricultural Experiment Station, and have been continued each succeeding year either at Cherryvale or at Manhattan.

ENVIRONMENTAL FACTORS INFLUENCING THE DISEASE

The fungus producing tomato wilt is dependent upon relatively high soil and air temperatures, combined with medium to high soil moistures, to bring about infection. Clayton found that the optimum soil temperature for the disease is approximately 28° C., while the air temperature must also be 28° C. or above for rapid death of infected plants.[3] Clayton also found that the soil in which tomatoes are grown must be at medium soil moistures for the most rapid development of the wilt.[4] If the soils were allowed to dry out the development of the disease was checked. If, on the other hand, the soils were nearly saturated, tomato plants growing therein were immune to attack. Apparently the effect of soil moisture is upon the fungus causing the wilt rather than upon the re-

3. Clayton, E. E. The relation of temperature to the Fusarium wilt of the tomato. Amer. Jour. Bot. 10:71-88. Pls. 8-11. 1923.

4. Clayton, E. E. The relation of soil moisture to the Fusarium wilt of the tomato. Amer. Jour. Bot. 10:133-147. Pls. 13-15. 1923.

sistance or susceptibility of the plants themselves. In very dry or in saturated soils apparently the organism cannot make sufficient growth to cause infection. Acid soils have been found to favor the disease,[5] although an acid soil is not necessary.

FIELD DATA

Extensive data have been obtained in Kansas on environmental factors in relation to the fungous wilt of tomato. During the course of these investigations large numbers of susceptible, semi-resistant, and resistant varieties of tomatoes have been grown. In 1921 maximum and minimum daily air temperatures were kept by recording the readings of standard mercury thermometers several times a day throughout the growing season. In 1922 a maximum and minimum thermometer was used for the same purpose. The 1923 records of daily maxima and minima air temperatures were obtained from the United States Weather Bureau at Manhattan, where most of the field experiments have been conducted for the past three years.

Maxima and minima soil temperatures were also obtained in 1921 and 1922 by reading, several times daily, standard soil thermometers. In 1923 a Freas soil thermograph was used for this purpose.

Precipitation records were kept for the three years throughout the growing season by means of a rain gauge similar to but smaller than the United States Weather Bureau type.

From a study of the data thus obtained and from the wilt behavior of both the susceptible and resistant varieties in the field and under controlled conditions in the greenhouse, some interesting relations between environmental factors and tomato wilt can be deduced. The data presented here substantiate the greenhouse results of Clayton[6] in that tomato wilt is favored by a high soil temperature and at least medium soil moisture. The relative influence of soil temperature and moisture could not be separated in uncontrolled field experimentation. It is worthy of note, however, that in 1921 the first general wilting and death of susceptible plants occurred during the first week of July, 14 days after a period of high temperatures (maximum reached on June 18) and high precipitation. In 1922 the most severe wilt period occurred the last of June and first of July, preceded by 20 days of high temperatures and 13 days after heavy rainfall. In 1923 two general wilt periods occurred. The first of these periods, the much more severe of the two, occurred

5. Sherwood, E. C. Hydrogen-ion concentration as related to the Fusarium wilt of tomato seedlings. Amer. Jour. Bot. 10:537-553. 1923.

6. Loc. cit.

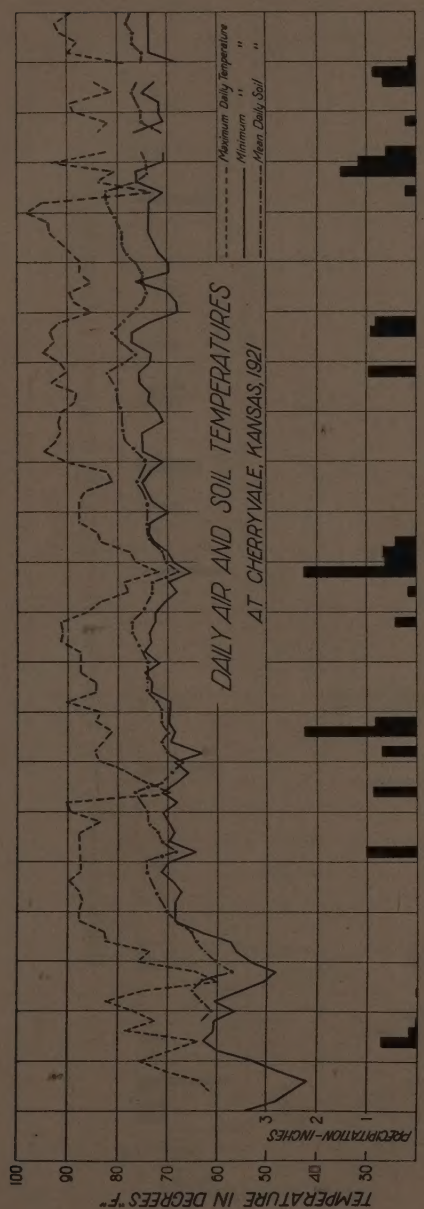


FIG. 3.—Graphs showing the daily air and soil temperatures and precipitation at Cherryvale, 1921.

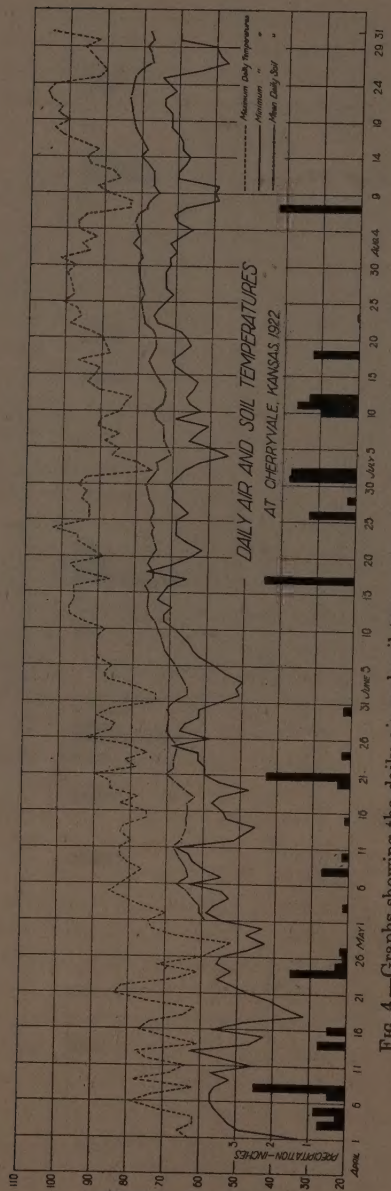

DAILY AIR AND SOIL TEMPERATURES
AT CHERRYVALE, KANSAS 1922
Maximum Daily Temperature
Minimum " "
Mean Daily Soil "
TEMPERATURE IN DEGREES F.
PRECIPITATION—INCHES
April 1 6 11 16 21 26 May 1 6 11 16 21 26 31 June 5 10 15 20 25 30 July 5 10 15 20 25 30 Aug 4 9 14 19 24 29 31

FIG. 4.—Graphs showing the daily air and soil temperatures and precipitation at Cherryvale, 1922.

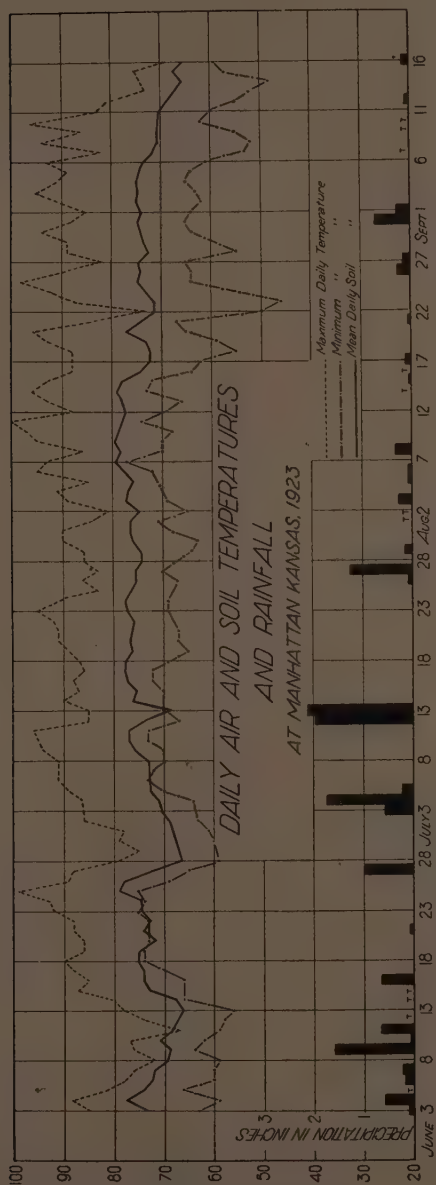


FIG. 5.—Graphs showing the daily air and soil temperatures and precipitation at Manhattan, 1923.

during the week of July 15, following high temperatures and high precipitation. The second occurred between August 6 and 13 and could not be so definitely associated with meteorological changes. However, the precipitation preceding the period was spread over several days and apparently kept the soil in an excellent condition for infection to occur. High temperatures also preceded and accompanied the wet period, but were not strikingly higher during the

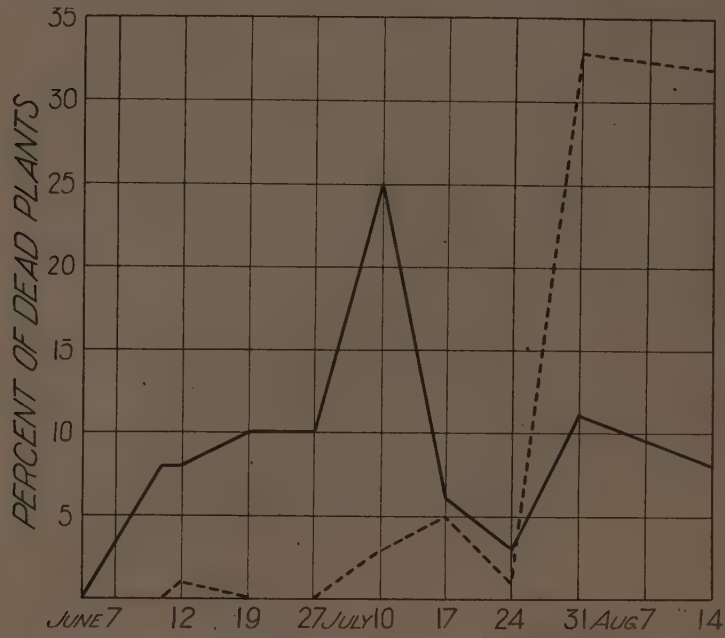


FIG. 6.—Graphs showing the per cent of wilt mortality by weekly periods for 1921. Of the susceptible varieties (solid line), 89 per cent were wilted at end of season. Of the resistant varieties (broken line), 75 per cent were wilted at end of season. Susceptible varieties included John Baer, Comet, Beauty, Grand Rapids, Bonny Best, Dwarf Champion, and Greater Baltimore. Resistant varieties included Louisiana Pink, Louisiana Red, Norton, Norduke, Marvel, Columbia, and Arlington. It will be noted that the maximum per cent of death of susceptible varieties was several weeks earlier than that for the resistant group.

preceding few days as was the case in 1921 and 1922 and the first period of 1923.

In 1924 meteorological records were not obtained in the field. It is interesting to note, however, in view of the absence of the disease during this season, that the precipitation records for Manhattan

show that the months of April to July, inclusive, were below normal, as compared to normal or above normal precipitation for the years 1921 to 1923, inclusive.

The first wilt period for each year, 1921 to 1923, inclusive, was marked by the early death of plants of susceptible varieties. The second wilt period was less distinct and resulted in the death of plants of more resistant varieties. This is clearly indicated when

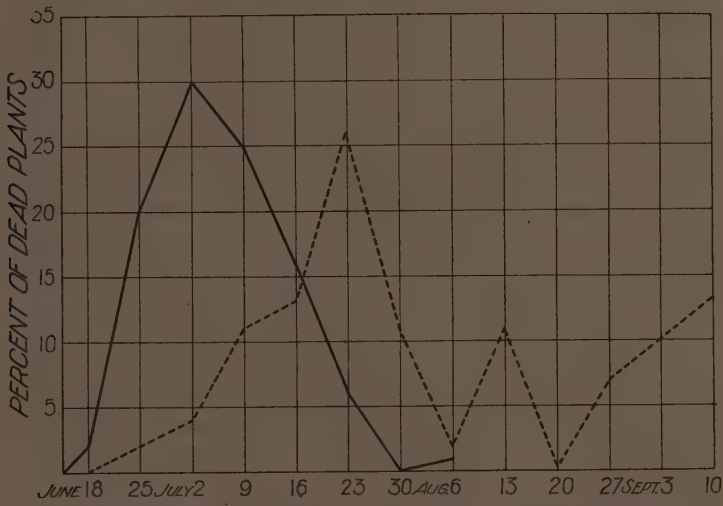


FIG. 7.—Graphs showing the per cent of wilt mortality by weekly periods for 1922. Of the susceptible varieties (solid line), 100 per cent were wilted at end of season. Of the resistant varieties (broken line), 94 per cent were wilted at end of season. Susceptible varieties included Bolgiano Capitol, Beauty, Comet, Grand Rapids, Dwarf Champion, Bonny Best, Bolgiano Red, Texas Belle, and a selection obtained from a member of the International Harvester Company. Resistant varieties included Louisiana Pink, Louisiana Red, Norton, Marvel, and Norduke.

the varieties are classed together in two groups, a resistant group and a susceptible group, as has been done in figures 6, 7, and 8 for the three years, 1921, 1922, and 1923, respectively.

Although field data on environmental influences are at best only suggestive, it is felt that these data are significant, especially in light of similar environmental studies based on greenhouse behavior that have been published.

GREENHOUSE DATA

Clayton's work on soil moisture in relation to tomato wilt under controlled conditions[7] is further substantiated by data obtained in studies on naturally infested soil kept at varying degrees of moisture by the use of Livingston's cone auto-irrigators. The water reservoirs were placed at three different heights in order to bring about three different soil moistures: one, very dry; one, very wet; and one,

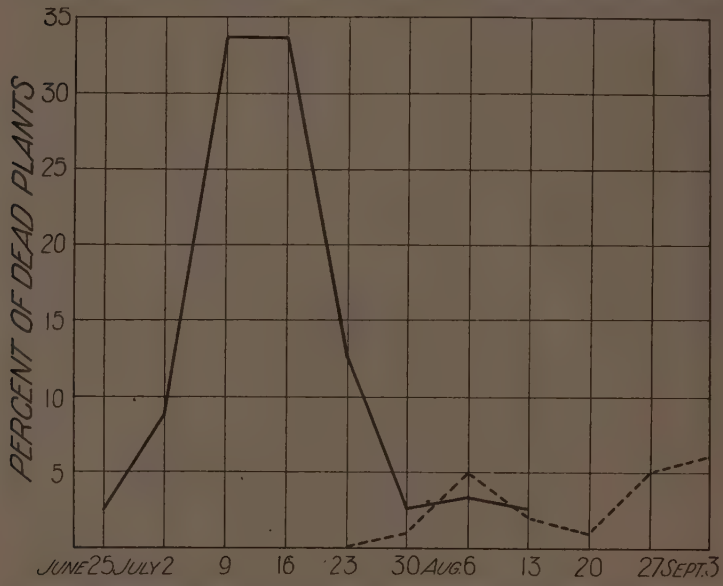


FIG. 8.—Graphs showing the per cent of wilt mortality by weekly periods for 1923. Of the susceptible varieties (solid line), 100 per cent were wilted at end of season. Of the resistant varieties (broken line), 22.4 per cent were wilted at end of season. Susceptible variety, John Baer. Resistant varieties included Louisiana Red, Louisiana Pink, Marvel, Norton, and Norduke.

intermediate in moisture content. For the high soil moisture series, the top of the reservoir was placed even with the bottom of the irrigator. For the medium soil moisture series, a water column of approximately 20 cm. was used, while a column of approximately 35 cm. was used for the low soil moisture series. Although all the reservoirs in a particular series were placed the same distance below the irrigators, wide variations in the moisture contents of the soil were noted. This may have been due to variations in the packing of

7. Loc. cit.

the soil about the irrigators or to differences in pore size or thickness of the irrigators themselves. At the time the pots were filled an attempt was made to pack the soil evenly and firmly about the irrigators. Slight variations, of course, could not be eliminated in this regard, but more than ordinary precautions were taken in filling the containers.

Seed of the Bolgiano Red tomato were planted directly in glazed pots and when the first true leaves were well grown, the plants were thinned to three in a pot. The surface of the soil was then sealed with a mixture of paraffin and vaseline. In all about 72 plants were grown at a temperature which fluctuated between 60° and 90° F.

Twenty-four days after the pots were sealed most of the plants in the medium soil moisture series were either dead from wilt or were showing signs of wilt. The plants were all taken from the pots at this time, examined, and those showing wilt symptoms were brought to the laboratory for culturing. *Fusarium lycopersici* was recovered from these diseased plants.

Soil moisture samples were taken in duplicate from each pot upon completion of the experiment. A range of soil moistures from 8.6 per cent to 37.6 per cent of the dry weight of the soil was found, individual pots varying from each other by 1 to 3 per cent. No wilt occurred in soil moistures below 18 per cent of the dry weight or above 27 per cent, indicating that medium soil moistures are necessary for wilt infection. It is realized that the number of plants used in this experiment was small and, therefore, the results open to question, but it is interesting to note that the general results are in agreement with the data obtained in the field.

VARIETAL RESISTANCE

Numerous wilt-resistant varieties have been developed by various Agricultural Experiment Stations and by the United States Department of Agriculture. They have been developed either by selection of normal tomato plants from fields of tomatoes in which the disease was severe, or by hybridization in which plants were used which had desired characters. Some resistant varieties are those developed by Dr. F. J. Pritchard of the United States Department of Agriculture, who has given the tomato industry the following varieties: Norton, Norduke, Marvel, Columbia, and Arlington; and who has recently distributed seed of three new varieties; namely, Marvana, Marvelosa, and Marglobe.

Dr. C. W. Edgerton of the Louisiana Agricultural Experiment

Station has developed two widely known wilt-resistant varieties; namely, Louisiana Red and Louisiana Pink.

These available wilt-resistant varieties, as well as some others from various Agricultural Experiment Stations, have been used in comparative trials in Kansas for the past seven years.

METHODS AND MATERIALS

Coöperative experiments on testing varietal resistance were begun in 1909 on the farm of Mr. O. W. Scott, of Cherryvale, Kan. At that time this was in the heart of the most severely infested region of the state. Mr. Scott coöperated in the experiments of 1919 to 1922, inclusive. In 1923, 1924, and 1925 similar experiments were conducted at Manhattan on artificially inoculated soil.

In all the varietal work conducted an attempt was made to subject the varieties as far as possible in field experiments to optimum conditions for infection. At Cherryvale, in addition to naturally heavily infested soil, a handful of old rotted diseased stems, saved from the previous year, was put around each plant as it was set in the field. All the plants were grown in the greenhouse in clean soil, transplanted once in flats and set in the field when eight to ten inches high. Only vigorous, healthy plants were set out in the field. In all the experiments the plants were trellised, pruned to one stem, and mulched. They were trellised because it had been found that trellised and pruned plants were much easier to study. Furthermore, more plants per unit area can be planted if these practices are followed. The mulch conserved soil moisture and kept the soil in more optimum conditions for infection. At Cherryvale a straw mulch of six to eight inches was applied as early as possible after the plants had become well established in the field. A bermuda grass hay mulch four to six inches thick was used at Manhattan. Ditch irrigation was resorted to at Cherryvale whenever drought conditions threatened and during the early part of 1924 irrigation was used at Manhattan.

The land available for the tomato work at Manhattan in 1923 had, as far as could be learned, never been in tomatoes. Consequently reliance had to be placed entirely upon artificial inoculation. A pure culture of *Fusarium lycopersici* originally isolated from a wilted plant from the plots at Cherryvale was grown in liter flasks on about 500 c. c. of steamed wheat kernels. A large quantity of such inoculum was prepared, and when the cultures were six weeks old it was thoroughly mixed with an equal quantity

of garden loam. A handful of the inoculum thus prepared was put around each plant as set in the field. Excellent results were obtained in getting infection.

In the fall of 1923 a barrel of diseased stems was mixed with enough garden loam and water to keep them moist to hasten decay. In the spring of 1924 this material was used as inoculum for each plant as set. An epidemic of leaf spot, caused by *Septoria lycopersici*, with unfavorable weather conditions for wilt infection, made the trials of 1924 unsatisfactory and very little wilt appeared. In 1925 inoculum consisting of pure cultures of *Fusarium lycopersici* was prepared as for 1923. Uniform infection was obtained throughout the plot.

As a check against varietal behavior to wilt, plants of the John Baer variety have always been used. It was known from the earlier experience of Mr. Scott that this variety was very susceptible to the fungous wilt. In 1925, Bonny Best, another very susceptible variety, was included as a check in addition to the John Baer plants. A list of the varieties that have been tested in Kansas in wilt-infested soil for one or more years and the original source of the seed follow:

Variety.	*Number of years tested.*	*Source of seed.*
Norton	7	F. J. Pritchard, U. S. D. A.
Marvel	6	F. J. Pritchard, U. S. D. A.
Columbia	6	F. J. Pritchard, U. S. D. A.
Arlington	6	F. J. Pritchard, U. S. D. A.
Norduke	6	F. J. Pritchard, U. S. D. A.
Marvana	2	F. J. Pritchard, U. S. D. A.
Marvelosa	2	F. J. Pritchard, U. S. D. A.
Marglobe	2	F. J. Pritchard, U. S. D. A.
Louisiana Red	5	C. W. Edgerton, La. Agr. Expt. Sta.
Louisiana Pink	5	C. W. Edgerton, La. Agr. Expt. Sta.
Comet	2	W. H. Underwood, Hutchinson, Kan.
Grand Rapids	2	W. H. Underwood, Hutchinson, Kan.
Tennessee Beauty	2	S. H. Essary, Tenn. Agr. Expt. Sta.
Greater Baltimore	1	Ohio Agr. Expt. Sta.
Greater Baltimore	1	O. S. Twilley, Hurlock, Md.
Bonny Best	2	Ohio Agr. Expt. Sta.
Dwarf Champion	2	Selection made at Hays, Kan., in 1920.
Bonny Best (Bolgiano)	1	Bolgiano Seed Company, Maryland.
Bolgiano Capitol	1	Bolgiano Seed Company, Maryland.
Bolgiano Red	1	Bolgiano Seed Company, Maryland.
Texas Belle	1	Texas Agr. Expt. Sta.
Unnamed	1	Representative of the International Harvester Co.
Missouri Red	2	J. T. Quinn, Mo. Agr. Expt. Sta.
Stone	1	Three selections from Ark. Agr. Expt. Sta.

In addition to these varieties, several hybrids with resistant and susceptible parents were made at the Kansas Agricultural Experiment Station and have been tested for their wilt resistance. Some

have proved of commercial value, especially a cross between John Baer and Norton, which has been named Kanora. (Fig. 1.) This hybrid has been spoken of as "Kansas 9B." A description of this hybrid and its merits is given on page 31.

EXPERIMENTAL RESULTS

Tomato Wilt Investigations, 1919

In 1919 seed of four varieties, Columbia, Arlington, Marvel, and Norduke was secured and planted at Cherryvale. The first two varieties were planted on infested soil, the last two on clean soil. They were trellised and pruned to a single stalk. The Columbia and

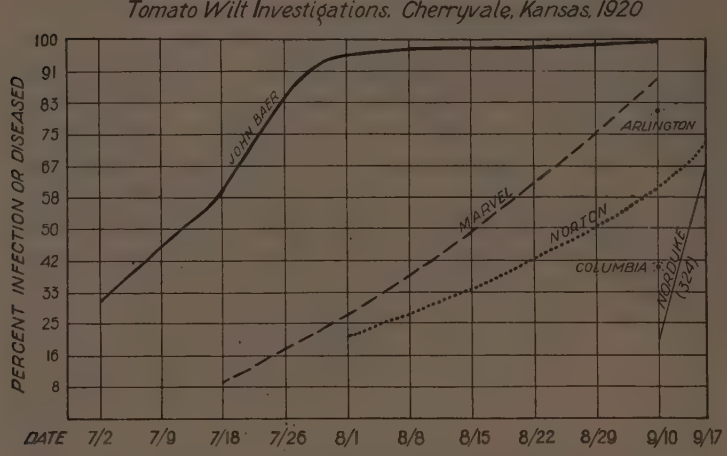


FIG. 9.—Graphs showing the wilt resistance of varieties grown in naturally infested and artificially inoculated soil at Cherryvale, Kan., 1920.

Arlington were found to be resistant to wilt, both varieties going through the season without the loss of a single plant. This was rather outstanding since the John Baer crop on this same ground was a total loss in 1919. Like the Norduke, these varieties proved to be midseason tomatoes and, therefore, too late for the main crop of tomatoes in this state. The fruit ripened much faster than the Norton and for this reason was not as desirable for home gardens, or markets, since it cannot be kept for any length of time. Both of these varieties are selections from the Greater Baltimore.

Marvel was not grown on infested soil in these tests, but was found to produce a good yield of medium early, smooth, deep red fruit.

The fruit was smaller than that of the other varieties tested and was the earliest-maturing variety grown.

Tomato Wilt Investigations, 1920

In 1920 the Marvel, Arlington, Columbia, Norton, and Norduke were grown at Cherryvale in badly infested soil. The following arrangement is in the order of their resistance: Norduke, Columbia, Norton, Arlington, and Marvel. (Fig. 9.) However, even the most susceptible of these five varieties, Marvel, was highly resistant when compared with John Baer. The first four varieties again proved to

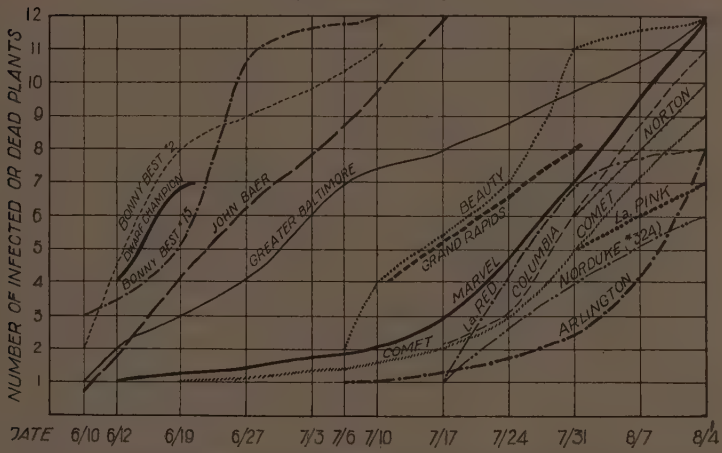


FIG. 10.—Graphs showing the wilt resistance of varieties grown in naturally infested and artificially inoculated soil at Cherryvale, 1921.

be midseason in maturity. While the Marvel was not quite as resistant as the midseason varieties, its earlier maturity would give it preference over them.

Tomato Wilt Investigations, 1921

Wilt was becoming so severe in Kansas by 1921 that increased efforts were made to secure more desirable wilt-resisting varieties and to use some of these as parents in hybridization studies. During the year 1920-'21 breeding experiments were started, the object being twofold: (1) to obtain a desirable wilt-resistant tomato through hybridization and through further selection within varieties, and (2) to study what constitutes wilt resistance in tomatoes.

Several new varieties were secured in addition to those which had already been grown. In all fourteen varieties were studied in 1921 at Cherryvale. These included the following: Norton, Marvel, Columbia, Arlington, Norduke, Comet, Grand Rapids, Tennessee Beauty, Greater Baltimore, and two strains, No. 2 and No. 15, of Bonny Best from Ohio, sent as wilt resistant. The John Baer variety was also grown as a check against the other varieties, the wilt resistance of which was unknown.

The experiments of 1921 proved to be very interesting. The season was favorable for the development of wilt, and a fair index as to the wilt behavior of the varieties under study was obtained. The varieties in general could be divided into two groups on a basis of their resistance or susceptibility. The susceptible group included John Baer, Greater Baltimore, Dwarf Champion, and both the selections of Bonny Best. The resistant group included the Arlington, Norduke, Louisiana Red, Louisiana Pink, Norton, Columbia, Marvel, and Comet. Two varieties, Tennessee Beauty and Grand Rapids, were intermediate in their behavior. (Fig. 10.)

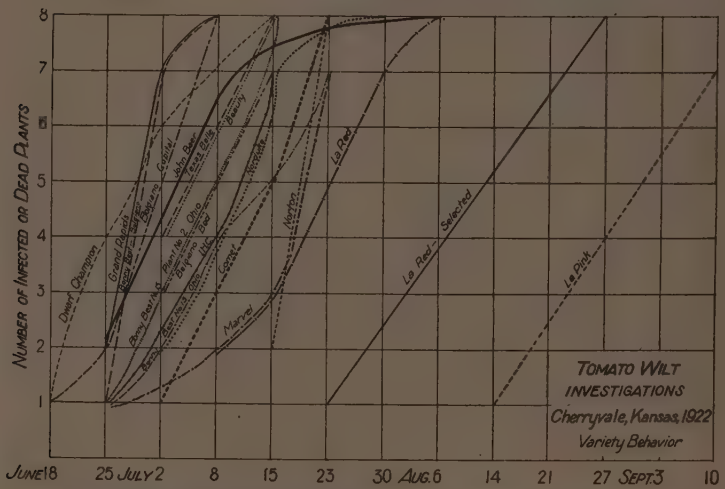


FIG. 11.—Graphs showing the wilt resistance of varieties grown in naturally infested and artificially inoculated soil at Cherryvale, 1922.

The Louisiana Red and Louisiana Pink were considered as being outstanding in wilt resistance, yield, and quality of fruit. Although later maturing than John Baer, Bonny Best, Earliana, or Chalk's

Jewel, the wilt-resistant character made them much more desirable. Wilt had become so severe in the southeastern part of the state that the tomato growers had to choose between an early-maturing, susceptible variety, or a slightly later-maturing variety more resistant to wilt. From the group of wilt-resistant varieties grown in 1921 the two Louisiana varieties, Marvel, Norton, and Norduke were the five most promising for Kansas growers. These varieties and others were continued in the field trials in 1922.

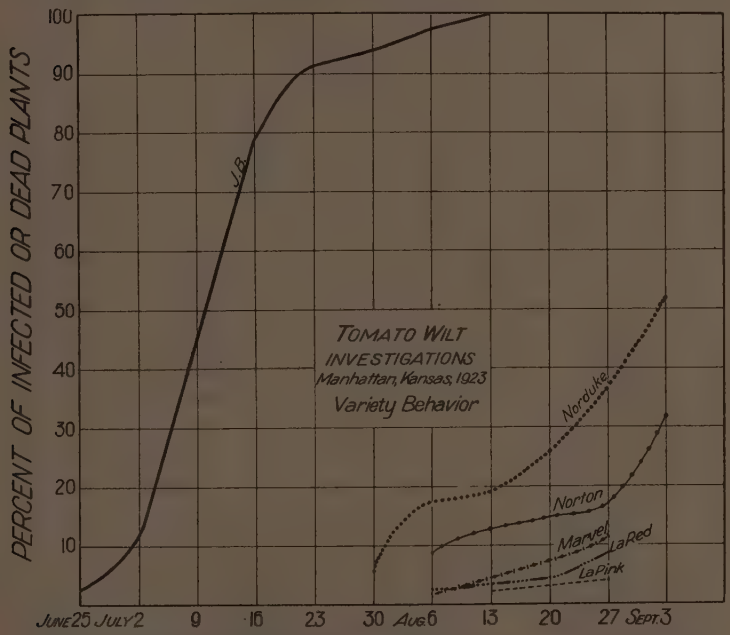


FIG. 12.—Graphs showing the wilt resistance of varieties grown on artificially inoculated soil at Manhattan, 1923.

Tomato Wilt Investigations, 1922

The season of 1922 was another very favorable year for the development of tomato wilt in the southeastern part of the state. The following varieties were added to those previously grown: Bonny Best (selection from Bolgiano Seed Company), Bolgiano Capitol, Texas Belle, Bolgiano Red, and a selection obtained from a representative of the International Harvester Company. (Fig. 11.)

These new varieties proved of little value. They were all found to be very susceptible to wilt under Kansas conditions. The Loui-

siana varieties again proved to be the most resistant varieties included in the tests. The Norton and Marvel followed in order, with the Norduke a poor fifth this season. The work of testing varieties over a period of years grew so rapidly with the advent of the advertised wilt-resistant varieties, that many of those tested this year and other years previous were discontinued. It was felt that a good index as to their varietal behavior toward this disease in Kansas was obtained and that more time should be spent with the most promising of the group. Consequently in 1923, the five most promising varieties were selected and the rest discarded.

Tomato Wilt Investigations, 1923

The larger part of the tomato wilt disease investigations were conducted this year on the experimental plots of the Agricultural Experiment Station at Manhattan. The five most promising varieties were selected from the previous year's results and planted in larger numbers than heretofore, for a more intensive study of their wilt-resistant character, yield, fruit size, etc. The varieties selected were the Louisiana Red, Louisiana Pink, Marvel, Norton, and Norduke. The seedlings were grown in the greenhouse in clean soil, transplanted once, and when about 10 inches tall set in the field after "hardening off." They were set in a handful of inoculum as previously described, trellised, pruned to a single stalk, and mulched. Fifty plants of Louisiana Red, Louisiana Pink, and Norton were set, and sixty of Norduke and Marvel. Some were lost in transplanting. Eighty plants of John Baer were interspersed with the varieties to act as a check upon their wilt behavior.

When compared with John Baer, a very susceptible variety, they all maintained their high degree of resistance. There was little difference this season among the two Louisiana varieties and Marvel when considering resistance alone. The Norton and Norduke did not prove to be quite as resistant as the other three varieties. (Fig. 12.) When grown on infested soil, the Louisiana Red yielded the highest, while the Marvel yielded the lowest. All five resistant varieties yielded much more than susceptible varieties, the latter being killed so early that practically no fruit matured.

The Norton produced the largest fruit, followed closely by the Norduke; both varieties produced fruit averaging slightly over six ounces. This is too large a fruit for the trucker, but it is not objectionable for home gardens. The Louisiana Red fruit averaged

approximately 5.5 ounces, the Louisiana Pink, 4.8 ounces and the Marvel, the smallest fruited variety of the five, averaged 4.5 ounces, a size more nearly the ideal for the market.

Tomato Wilt Investigations, 1924

In 1924 the varietal tests were again conducted at Manhattan. The following varieties were included: Marglobe, Marvelosa, Marvana (three new early wilt-resistant varieties from the United

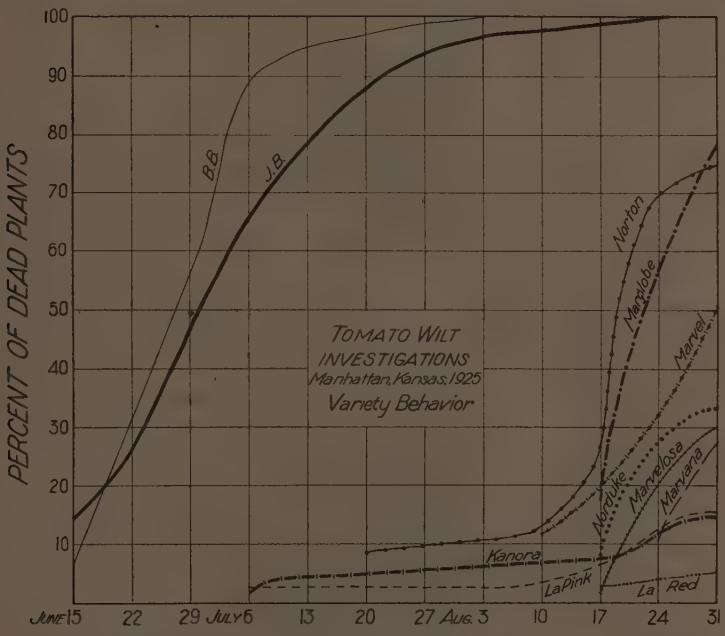


FIG. 13.—Graphs showing the wilt resistance of varieties grown in artificially inoculated soil at Manhattan, 1925.

States Department of Agriculture), Missouri Red, three selections of Marvel (one of which was made in Missouri), three selections of Norton (one which originated in Missouri), four selections of Norduke, two selections of Louisiana Pink, and three selections of Louisiana Red. John Baer was used as a check as in previous years.

Very little wilt showed up in the experimental plot during the season of 1924, in spite of the fact that each plant was set in a handful of inoculum as described in previous experiments. The

season of 1923 produced a field of tomatoes uniformly diseased with wilt and all the diseased vines were allowed to rot on the ground. The soil was known, therefore, to be heavily infested. A severe epidemic of leaf spot, combined with an infestation of red spider, made the diagnosing of wilt from external symptoms very difficult. Since an accurate record of fruit production was being made an internal examination of suspicious looking plants was impossible.

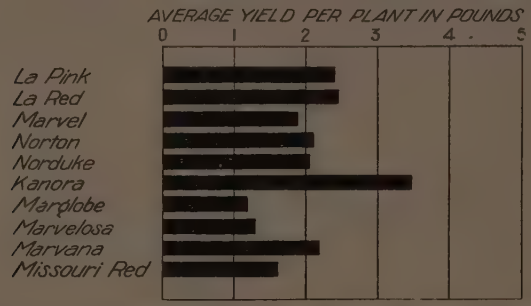


FIG. 14.—Graphical representation of the average yield of wilt-resistant varieties grown in heavily infested soil, 1923 to 1925. Marglobe, Marvelosa, Marvana, and Missouri Red were grown for two years only, 1924 to 1925.

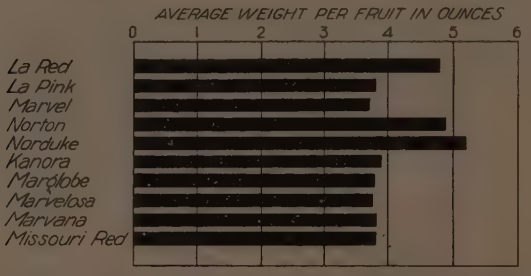


FIG. 15.—Graphical representation of the average weight per fruit of wilt-resistant varieties grown at Manhattan, 1923 to 1925. Marglobe, Marvelosa, Marvana, and Missouri Red were grown for two years only, 1924 to 1925.

While no data were obtained as to the wilt resistance of the several selections, data on comparative yields, on fruit size, and date of maturity were secured. This information is valuable for the market gardener. A severe epidemic of leaf spot caused by *Septoria lycopersici* Speg. and a heavy infestation of red spider followed by a large amount of soft rot, cut down the total yields very materially in 1924.

Marvel, Marglobe, and Marvana were also grown at Cherryvale in heavily infested soil. The Marvel, as in previous experiments, and the Marglobe, while being resistant, proved to be early mid-season varieties. The Marvana, however, proved to be highly resistant to wilt, very productive and very early, fully a week earlier than John Baer. From this year's experience with this variety at Cherryvale, it seems to offer exceptional possibilities for certain sections of Kansas. While Marvana was proving highly resistant to wilt in Cherryvale and yielding an early and heavy crop, it was proving less desirable commercially at Manhattan owing to a lower yield.

Tomato Wilt Investigations, 1925

Varietal tests were again conducted at Manhattan in 1925. The following varieties and selections were included this year, properly checked by John Baer and Bonny Best plants: Louisiana Pink, Louisiana Red, Kanora, Marglobe, Marvelosa, Marvana, Marvel, Norduke, Norton, Missouri Red, and three selections of Stone received from the Agricultural Experiment Station of Arkansas.

As shown in figure 13, all these resistant varieties retained their resistance when compared to either of the susceptible varieties grown as checks. The three selections of Stone received from Arkansas proved resistant under Kansas conditions, but were very light-yielding strains, and could not be recommended to Kansas growers for that reason.

As in 1924 the yield was reduced materially by an outbreak of red spider. The 1925 outbreak threatened the entire experiment but the pests were satisfactorily checked by the use of Sunoco Oil Emulsion spray used three times, approximately a week apart.

The commercial desirability of a variety, however, is determined upon yield, size and quality of fruit, as well as disease resistance. In figures 14 and 15 are presented data showing the average yield of the wilt-resistant varieties and average fruit weight for a three-year period, 1923 to 1925, inclusive.

SUMMARY OF VARIETY TESTS

It should be emphasized that the yields of all varieties tested have been low due to the fact that they have been grown on relatively poor ground heavily infested with the wilt organism.

When grown in heavily infested soil Kanora (fig. 1) has outyielded all other varieties and selections followed by Louisiana Red, Louisiana Pink, Norduke, Marvana, Norton, and Marvel in the order named.

TABLE I.—Yield of certain wilt-resistant varieties of tomatoes and certain wilt-susceptible varieties grown under good commercial care, in disease-free soil, at Manhattan, 1921 to 1924, inclusive. (*a*)

VARIETY (*b*).	Pounds per plant of marketable fruit.				
	1921.	1922.	1923.	1924.	Average.
Kanora (Kansas 9B).....(R)	.....	.....	6.05	5.19	(*c*) 5.62
Louisiana Red.....(R)	1.93	9.17	5.71	4.25	5.24
Louisiana Pink.....(R)	3.32	5.57	6.23	5.04	5.04
Norduke.....(R)	1.10	5.03	4.33	3.01	3.37
Marvel.....(R)	0.77	5.05	.....	.....	(*d*) 2.91
Bonny Best.....(S)	3.32	4.55	4.40	5.83	4.52
John Baer.....(S)	3.97	5.72	3.70	4.50	4.48
Chalk's Early Jewell.....(S)	4.18	.....	4.36	4.10	4.16
Earliana.....(S)	3.89	2.72	3.28	4.33	3.55

(*a*) The data presented in this table were collected by Mr. W. B. Balch, Assistant Professor of Horticulture, to whom credit is due.

(*b*) R—resistant; S—susceptible.

(*c*) Yield records for two years only are available for Kanora. This variety is a hybrid in the F_6 generation. During the years 1921 to 1922 selections were not sufficiently fixed for the characters of resistance, production, etc., to justify their use in a test conducted primarily for yield.

(*d*) The Marvel variety was grown for two years only.

COMMERCIAL TESTS OF VARIETIES

Many of these wilt-resistant varieties have been grown by Mr. W. B. Balch of the Department of Horticulture in varietal and cultural tests. The average yield of these as well as certain wilt-susceptible varieties over a four-year period is given in Table I. These data show what wilt-resistant varieties will do under good commercial conditions in wilt-free soil.

REACTION OF HYBRIDS TO THE FUNGOUS WILT DISEASE

The wilt-resistant varieties tested in the years 1919 and 1920 were found to be much less desirable from a commercial viewpoint as regards fruit characters and yield, than the selected strains of John Baer and other varieties previously grown. Some hybridization work was undertaken in an effort to include the fruiting habits of John Baer and the resistance to wilt of one of the other varieties, thereby attempting to produce a high-yielding, early, wilt-resistant hybrid.

In 1920 and 1921 crosses were made in the greenhouse between resistant and high-yielding varieties by Mr. C. O. Johnston of the Agricultural Experiment Station. John Baer was used as the parent possessing the desirable fruiting qualities and Norduke and Norton

as the parents possessing high resistance to wilt. Reciprocal crosses were made but for the most part John Baer was used as the male parent. Blossoms were emasculated before the petals had parted and while the pollen sacs were still immature. Artificially pollinated stigmas were protected from chance cross pollination by glassine envelopes until evidences of development of the young fruits were observed. Twenty-three such crosses were made and seed of them sent to Cherryvale for field trials. Several hybrids were lost owing to the late date that they were set out in the field. None of the hybrids in the F_1 were planted in infested soil.

During the winter of 1921-'22, six of the most promising hybrids from a horticultural standpoint were grown in the greenhouse, selfed, and seed saved for field trials in 1922. By this method two crops could be grown each year and this aided in the study of the hybrid material. The F_2 generation was grown in the greenhouse, while the F_3 generation was tested in the field the following summer.[8]

Consequently in 1922, fourteen families in the F_2 generation and six families in the F_3 generation were tested at Cherryvale in badly infested soil. Each plant was also artificially inoculated with a handful of decayed diseased stems. Eight plants of each family were grown in this soil, trellised, pruned to a single stalk, and mulched.

In 1922 all the hybrids studied were found to be susceptible in F_2 generation, nearly all plants being dead from wilt by the last of July, although some stood up much longer than others. In the F_3 generation the same results were obtained with the exception of a selection from hybrid No. 9, plant B, later known as "9B." This showed no signs of wilt until July 30, and it was not until August 27 that all the plants were dead. One died from the effects of leaf blight, *Septoria lycopersici*, and not from wilt. It is interesting to note that another selection from the same family made in the F_2 generation and called "9A" has proved susceptible in all trials.

From the hybrids in the F_3 generation, one selection was made of No. "9A" and three selections from No. "9B." As in 1922 "9A" proved to be susceptible in 1923, but all three selections of "9B" in the F_4 generation continued to show marked resistance. This hybrid, which is a cross between Norton and John Baer, using the former for the female parent, is in the sixth generation, and is breeding true for the character of wilt resistance. This hybrid is

8. No attempt was made to study the population of the several hybrids genetically.

being distributed to tomato growers as a desirable wilt-resistant variety of tomato for Kansas growers. It has been named "Kanora." (Fig. 1.)

TESTS WITH GROWERS

In conjunction with the varietal work at Manhattan and Cherryvale, it has been the aim each year to send to coöperating tomato growers seed of the most desirable wilt-resistant varieties for trials. Replies from those to whom seed have been sent indicate that the resistant varieties sent them have, on the whole, given satisfac-

FIG. 16.—Bonny Best tomato, a wilt-susceptible variety, grown in heavily infested soil at Cherryvale, 1922.

tion. The Louisiana Red and Louisiana Pink varieties have proved most desirable, the only criticism by large growers being that these varieties do not produce fruit as early as is desired. The reports state that they are anywhere from a few days to three weeks later in maturing the first fruit than Earliana or Chalk's Early Jewel. While this is an undesirable feature, it is greatly overbalanced by their wilt resistance, which frequently means a crop of tomatoes or none at all where such varieties as Earliana, John Baer, or Chalk's Early Jewel are grown.

GENERAL CONSIDERATIONS

The greatest prerequisite which a tomato variety must have for Kansas is its resistance to the fungous wilt disease. This disease is fast becoming the limiting factor in tomato production in this state. It is already the limiting factor on most of the commercial acreage. The problem is an important one, because once the soil is infested effective control can be obtained only through the growing of resistant varieties or the use of long rotations.

During the progress of these investigations on varietal resistance, twenty-nine varieties and strains of tomatoes have been grown in

FIG. 17.—The Louisiana Red tomato, a wilt-resistant variety, grown in heavily infested soil at Cherryvale, 1922. Plants on extreme ends are checks of John Baer variety.

order to study their reaction to wilt. Of these twenty-nine varieties a few have been found that are adaptable to Kansas conditions. In addition to testing varieties, some hybrids have been made which promise to be of considerable value. One of these has been named the Kanora tomato (Kansas 9B), a new wilt-resistant variety. (Fig. 1.)

The studies in Kansas indicate that varieties resistant under one set of conditions may be less resistant or even susceptible under another set of conditions. This is borne out by the fact that varieties highly resistant in other states have given very unsatisfactory results under Kansas conditions. It is necessary only to note

the extreme susceptibility of the Bonny Best wilt-resistant selections received from the Agricultural Experiment Station of Ohio when grown under Kansas conditions. (Fig. 16.) Whether this is due to variations in climatic influences on the host or on the pathogen, or whether distinct physiological races of the organism exist, remains to be proved, and investigations upon this problem are well advanced.

It is important to bear in mind, therefore, that some varieties now considered as wilt-resistant for Kansas conditions may vary in their behavior as time goes on. How long a variety will remain resistant is problematical. It may be found necessary to develop resistant varieties for different localities in the state, but the present investigations have not included a close study of these factors. It is believed that studies on varietal behavior and the production of other hybrids should be continued in order to meet conditions as they arise.

VARIETIES OF TOMATOES SUITABLE FOR KANSAS GROWERS

LOUISIANA RED

This variety is a hybrid between a wilt-resisting selection of Acme (?) and Langdon's Earliana. Louisiana Red is highly resistant to wilt in Kansas, productive, with medium to large deep red fruit. It is a very desirable variety for the home garden, or for local market, although it is a midseason variety. (Fig. 17.)

LOUISIANA PINK

This variety is also a hybrid between a wilt-resistant selection of Acme (?) and Langdon's Earliana. It is the most resistant variety tested in Kansas since these investigations were begun in 1919. It is a vigorous, productive variety; producing medium to large, meaty and firm pink fruit. This variety makes a fine one for home gardens. It is not desirable for most of the trucking districts, owing to unwarranted discrimination against all pink varieties of tomatoes. It is a midseason variety.

MARVEL

This variety is a selection from a French variety of tomato, Merveille des Marchés (marvel of the market). While not quite as resistant as the Louisiana varieties, it is tolerant to the wilt disease, does well in heavily infested regions, and is an earlier-maturing variety than any of the other wilt-resistant varieties, with the exception of the Marvana. It is a very productive, vigorous,

medium-large plant, producing good crops on infested soil, of a medium-sized, bright red, deep fruit. This variety is recommended for home gardens and truckers. It also may be used for greenhouse culture where wilt is troublesome.

NORTON

This variety is a selection from Stone. It is very resistant to wilt, but a late variety which excludes it from use for market gardeners in general. It is a very slow ripening, firm, bright red, deep fruit, excellent for a late variety for the home garden and for canning purposes.

NORDUKE

Norduke is a hybrid between Norton and Duke of York. It is a midseason, large-fruited variety. Although not as resistant in Kansas as other varieties, it will mature the main part of the crop before the plants die of wilt. For a midseason variety, however, the Norton, Louisiana Red, or Marvel is preferable for Kansas growers.

MARVANA

Marvana is a hybrid between Marvel and Earliana. Although this variety is a recent introduction, having been given only two years' trial in Kansas, its outstanding earliness combined with wilt resistance deserves mention. It is by far the earliest of any wilt-resistant variety tested. It has also shown a high degree of resistance to wilt in the southeastern part of the state. It proved more resistant to this disease in 1924 than Marvel, and more productive of a high-quality fruit. It outyielded all other varieties in trials at Manhattan in 1924 with an average fruit size of four ounces. In 1925, however, it was surpassed in yield by the Kanora, Louisiana Pink, and Louisiana Red varieties.

KANORA

Kanora is a hybrid between Norton and John Baer, made in 1921. Selections were made from the original cross by Mr. O. W. Scott of Cherryvale. It has been fixed in desirable characters by careful selection from year to year. It is a variety having the fruit qualities of the John Baer, medium to large, deep red and very productive. It has proved very resistant to wilt, but no more resistant than its resistant parent, Norton. It has outyielded the Norton in 1923, 1924, and 1925, and the fruit was smaller and more uniform, making it more desirable. The large size (6.3

ounces in 1923; 4.9 ounces in 1924; 3.9 ounces in 1925) of the fruit of the Norton makes it less desirable for truck gardening than the Kanora, producing fruit which for the same three years averaged 4.7, 3.5 and 3.3 ounces, respectively. Healthy, vigorous plants, well loaded with fruit, as shown in figure 1, are the rule with this variety.

CONCLUSIONS

Tomato wilt annually causes a large loss to the tomato growers of Kansas. This disease is caused by a fungus, *Fusarium lycopersici* Sacc., and can be controlled effectively only by growing resistant varieties or practicing long rotations. The latter method is impractical and frequently impossible to practice.

Twenty-nine varieties of tomatoes have been tested under Kansas field conditions for resistance to wilt. The majority have proved wilt-susceptible in spite of the fact that they have been described as resistant varieties.

Six varieties introduced into the state for trial purposes and one developed at this station have proved wilt resistant, commercially desirable, and climatically adapted to Kansas. They are Louisiana Red, Louisiana Pink, Marvel, Norton, Norduke, Marvana, and Kanora.

For the market gardener who desires an early, red tomato, the Marvel is recommended. Although Marvana surpassed other wilt-resistant varieties in 1924 and is very promising, more experience with it is necessary under different environmental conditions before it can be unqualifiedly recommended.

For the home garden, Marvel, Louisiana Red, Norton, and Kanora are recommended. The Louisiana Pink also is a very fine tomato for home use for those desiring a pink-skinned variety.

Varieties classed as resistant may prove to be somewhat susceptible when grown under certain other environmental conditions.

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